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R. D. NEIFELD

MAY 2001

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
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13. ABSTRACT *(Maximum 200 words)*

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EROSION EFC FACTORS FOR KINETIC ENERGY ROUNDS USED IN THE 120-MM M256 TANK CANNON

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The U.S. Army and Air Force's standard manual for the evaluation of cannon tubes designates fatigue condemnation criteria for each cannon tube type. It also designates erosion condemnation criteria for each cannon tube type, and designates a cartridge/zone fatigue effective full charge (EFC) factor for each charge/projectile combination. These criteria help in cannon inventory management. However, the manual lacks a designated cartridge/zone erosion EFC factor for each charge/projectile combination. This represents a notable technology gap for tank and artillery cannon systems, since erosion condemnation occurs much quicker than fatigue condemnation when using the latest charge/projectile combinations. Our report outlines a detailed computational and experimental method using the Unified Cannon Erosion Code to compute a cartridge or round erosion EFC factor for the M865, M829, M829A1, and M829A2 kinetic energy round types used in the 120-mm M256 tank cannon at multiple round-conditioning temperatures. Our report further outlines the obvious extension of this method to any group of charge/projectile combinations used in a specific tank or artillery cannon. The following erosion EFC factors are based on an erosion EFC factor of 1.0 for the M865 round type at a 21°C round-conditioning temperature as requested by PM-TMAS. These erosion factors correspond to a peak erosion location approximately 2.2 meters from the rear face of the tube. For the M865, M829, M829A1, and M829A2 round types at a 49°C round-conditioning temperature, the respective erosion EFC factors are approximately 1.5, 4.2, 5.0, and 6.3. Similarly, the respective erosion EFC factors are approximately 1.0, 2.8, 3.3, and 4.2 at a 21°C round-conditioning temperature, and the respective erosion EFC factors are approximately 0.7, 1.9, 2.2, and 2.8 at a -32°C round-conditioning temperature. The respective erosion EFC factors are approximately 1.1, 3.0, 3.5, and 4.4 for an equal distribution of these three round-conditioning temperatures. M256 cannon fatigue life and fatigue EFC factors are officially specified in the above technical manual and help the Army manage its M256 inventory. They are not round type or conditioning temperature-dependent. M256 cannon erosion life and erosion EFC factors are unofficially specified in this work, and will further help the Army manage its M256 inventory. They are both round type and conditioning temperature-dependent. M256 cannon erosion-related inventory management is important, since its erosion life can be up to an order of magnitude more limiting than its associated fatigue life.

14. SUBJECT TERMS
Gun Barrel Erosion, Kinetic Energy Round EFC Factors, Kinetic Energy Round Erosion, 120-mm M256 Tank Cannons

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13. ABSTRACT *(Maximum 200 words)*

The electrolytic deposition of chromium on the bore of thick-walled, high-pressure cylinders uses a lead-tin alloy as the anode for the plating process. The anode is prepared by melting a lead-tin solder over a cylindrical copper core, which is then machined to the proper diameter. Using differential scanning calorimetry, the melting temperature of various ratios of lead-tin can be measured and a portion of the phase diagram can be established between the solid and liquid states. The melting temperature of a solder can then be measured and the composition can be obtained from the phase diagram.

14. SUBJECT TERMS

Thermal Analysis, Lead-Tin Alloy, Differential Scanning Calorimetry, Inductively Coupled Plasma Emission Spectroscopy

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G. Pflegl, and C. Rickard

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13. ABSTRACT (*Maximum 200 words*)

The preliminary experimental 120-mm M829E3 kinetic energy round data described here represent a stage in the development cycle that occurred about a half year to a year ago. The computational erosion predictions are guided and supported by substantial field and laboratory data, including data from firing tests, laboratory tests, and nondestructive/destructive cannon erosion characterizations. This information is intended to provide a "snapshot" of development for that period, and is not directly related to the future type-classified M829E3 kinetic energy round. During that period, these modeling predictions put the program about 40 rounds shy of its required 180-round minimum program target, so further round optimization will likely contribute to the achievement of this goal. Further round optimizations will likely include changes in the weight and configuration of the propellant, projectile, case, and possible ablative. Results of this erosion analysis, erosion effective full charge factor analysis, and comparisons to the round's advanced type-classified counterpart are provided for the preliminary experimental M829E3 kinetic energy round used in the 120-mm M256 cannon at multiple round-conditioning temperatures. The computational method consisted of using our Unified Cannon Erosion Code. Differences exist between the preliminary experimental M829E3 kinetic energy round and its advanced type-classified counterpart including increased propellant weight, increased projectile weight, and RPD380 propellant instead of JA2 propellant. The preliminary experimental M829E3 kinetic energy round erosion analysis achieves erosion condemnation in a lesser number of rounds, and the worst eroded region has moved slightly more than a half meter up-bore compared to its advanced type-classified counterpart.

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Cannon Erosion Analysis, Experimental M829E3
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13. ABSTRACT (*Maximum 200 words*)

Cellular automata simulations can be used to capture many of the essential features of processes that are difficult to model. They are particularly useful in the study of nonlinear dynamical systems that have complex continuous solutions. In this study, cellular automata models have been employed to investigate the nature of the vapor deposition process by exploring the natural evolution of dynamical dissipative systems using self-organized critical system analysis and spatial scaling measures. A new numerical technique is introduced to analyze the intrinsic structure of evolving surface topography in an effort to better understand the dynamics of the growth processes. This technique is being used to validate the integrity of deposition models through a comparative analysis with experimental data and to determine if a correlation exists between intrinsic surface structure and parameters controlling the deposition process.

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6. AUTHOR(S)

D. Windover (Benet and RPI, Troy, NY), T.-M. Lu (RPI), S.L. Lee, A. Kumar (SUNY Albany), H. Bakhru (SUNY Albany), C. Jin (Texas Instruments, Dallas, TX), and W. Lee (Texas Instruments)

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13. ABSTRACT *(Maximum 200 words)*

X-ray reflectivity has been used to nondestructively measure the density of thin, porous, SiO_2-based xerogels. Critical angle, defined by total external reflection, was measured for multiple x-ray energies to correct for sample misalignment error in the determination of the density for the films. This density was used to extrapolate the percentage of porosity, assuming a bulk SiO_2 density standard. The results were compared to those obtained by Rutherford backscattering and ellipsometry techniques.

14. SUBJECT TERMS

X-Ray, Reflectivity, Xerogels, Density

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13. ABSTRACT *(Maximum 200 words)*

In June 1999, Dr. Cote supplied a prepublication copy of his and Mr. Rickard's report, "*Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces*," and requested this author's comments. These comments are offered here.

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13. ABSTRACT *(Maximum 200 words)*

Results are presented of a scanning electron microscope fractographic study of a circa AD83 iron nail from the Roman fortress at Inchtuthil, Perthshire, Scotland. The fracture surface studied was created under embrittling conditions of low temperature, an added stress raiser, and high strain-rate loading. Fractographic features are discussed in relationship to the classic cataloguing and metallographic examination of the Inchtuthil nails in earlier work by Angus, Brown, and Cleere.

14. SUBJECT TERMS
Scanning Electron Fractography, Roman Nail,
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13. ABSTRACT *(Maximum 200 words)*

The present report is a reply to J.H. Underwood's critique of the ARDEC Technical Report entitled "Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces" by Cote and Rickard. At issue is the evidence from the survey study by Cote and Rickard, that hydrogen cracking plays no role in damage initiation and chromium spallation.

A brief review of the controversy relating to hydrogen cracking and damage initiation in gun bores is presented here. The question of hydrogen cracking beyond the initiation stage is also addressed. Consideration of some of the implications of the proposed hydrogen-cracking model and the general observations of the survey study offer reasons to doubt that damage initiation in gun bores is a result of hydrogen cracking, despite the plausibility of the proposed model.

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Gray Layers, Hydrogen Cracking, Chromium Spallation, Erosion, Damage Initiation	12
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6. AUTHOR(S)

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13. ABSTRACT *(Maximum 200 words)*

Never has the need for simulation in design of components been more acute. Today's business environment requires innovative thinking in product development, especially for the 'big-ticket' ordnance items such as main battle tanks and armament. The manufacturing costs of these items and related components prohibit use of the classical method of product development, which includes initial design, prototype manufacture, system testing, and redesign. The answer lies in the use of virtual performance simulation to assess a system's response before any hardware is manufactured. Up-front costs are greatly reduced since the system components reside in virtual space, allowing for rapid electronic design changes and optimization by simulation rather than iterative testing of costly hardware.

One must not be overly enamored by the power and function of the simulation tools. They are just mathematical models written by mere mortals, the execution of which closely mimics nature but does not actually reproduce it. Ultimately, these simulations need to be validated before one becomes comfortable in their use. There are various ways to validate a simulation code. First, one may use dedicated and controlled tests void of extraneous noise to establish relational characteristics among a few test variables. The results may then be directly compared to simulations, with validation achieved when output closely matches the test data. The second method involves comparing simulated results to inherently noisy field-generated test data. The best one may expect to achieve from this type of validation is trends in the responses relative to variations in the system parameters. It is the purpose of this report to validate a coupled simulation package for the accuracy assessment of large caliber weapons. The simulation packages include SIMBAD, a finite element gun dynamics code, and BOOM, a projectile flight dynamics code. These two models have been coupled so that the output of SIMBAD is the input to BOOM. Simulated results are compared to field-generated accuracy firings for the M1A1 tank, thus method two validation was used to assess the worth of this endeavor.

14. SUBJECT TERMS

Gun Dynamics, Tank Gun Accuracy, Flexural Body Dynamics,
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STRESS AND FATIGUE LIFE MODELING OF CANNON BREECH CLOSURES INCLUDING EFFECTS OF MATERIAL STRENGTH AND RESIDUAL STRESS

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6. AUTHOR(S)
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Laboratory fatigue life results are summarized from several test series of high-strength steel cannon breech closure assemblies pressurized by rapid application of hydraulic oil. The tests were performed to determine safe fatigue lives of high-pressure components at the breech end of the cannon and breech assembly. Careful reanalysis of the fatigue life tests provides data for stress and fatigue life models of breech components, over the following ranges of key parameters: 380 to 745 MPa cyclic internal pressure; 100 to 160-mm bore diameter cannon pressure vessels; 1040 to 1170 MPa yield strength A723 steel; no residual stress; shot-peen residual stress; overload residual stress.

Modeling of applied and residual stresses at the location of the fatigue failure site is performed by elastic-plastic finite element analysis using ABAQUS and by solid mechanics analysis. Shot-peen and overload residual stresses are modeled by superposing typical or calculated residual stress distributions on the applied stresses. Overload residual stresses are obtained directly from the finite element model of the breech, with the breech overload applied to the model in the same way as with actual components. Modeling of the fatigue life of the components is based on the fatigue intensity factor concept of Underwood and Parker, a fracture mechanics description of life that accounts for residual stresses, material yield strength, and initial defect size.

The fatigue life model includes six test conditions in a stress versus life plot with an R^2 correlation of 0.94. The model shows significantly lower correlation when known variations in yield strength, stress concentration factor, or residual stress are not included in the model input, thus demonstrating the model sensitivity to these variables.

14. SUBJECT TERMS
Fatigue Life, Cannons, Finite Element Analysis,
Stress Modeling, Fatigue Life Modeling, Residual Stress

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*
Two-dimensional image plate applications in x-ray diffraction and x-ray reflectivity characterization, using grazing-incidence geometry and radiation from a conventional x-ray tube, were explored. X-ray diffraction and x-ray reflectivity data were obtained from a conventional diffractometer with Si(Li) detector. These data complement image plate results to give more complete phase and structure information. Protective chromium coatings, electrochemically deposited onto the bore of steel cylinders, were investigated. Retained austenite content in martensitic steel was measured in simulated, inside-diameter, bore geometry. This approach demonstrates the versatility of the method for nondestructive chemical analysis and phase differentiation of interior bore surfaces in piping structures. MATLAB-based processing software was developed to facilitate quantitative image analysis, including multiple 2θ scans, χ-plots, and pole figure reconstruction from multiple φ images, where χ and ϕ designate, respectively, specimen tilt and rotation. In x-ray reflectivity applications, 12-nm tantalum and 80-nm tantalum oxide thin films sputtered on (100)-oriented silicon wafers were investigated. Density and thin-film thickness were obtained from specular reflectivity modeling involving the periodicity of the interference fringes. Two-dimensional Kiessig interference-fringe images were analyzed and compared to conventional specular x-ray reflectivity images for the measurement of thin-film thickness and thickness uniformity over a sample.

14. SUBJECT TERMS
Digital Film, Image Plate, Chromium, Tantalum, Tantalum Oxide, Austenite, Martensite, Coatings, Thin Films, X-Ray Diffraction, X-Ray Reflectivity

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

An x-ray digital image plate detector was used to conduct phase and texture analyses of thin tantalum films in several seconds using a conventional, fixed copper anode, x-ray tube. This plate imaging method provides an expansion of grazing-incidence x-ray diffraction, out of the goniometer plane. The method exploits Laue flat plate geometries and "tall" Debye-Scherrer camera methods. The film studied shows 200-nm of sputter-deposited, α-phase tantalum, showing <110> fiber texture grown on a silicon (100) substrate. Image plate texture information was presented, and confirmed through comparison with conventional pole figure and 2θ Bragg analyses.

14. SUBJECT TERMS
Image Plate, Digital Films, Tantalum, Phase, Texture

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13. ABSTRACT *(Maximum 200 words)*

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EFFECT OF SPUTTERING PARAMETERS ON
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5. FUNDING NUMBERS

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13. ABSTRACT *(Maximum 200 words)*

Tantalum offers a number of attractive properties for gun bore coating applications, including a high melting temperature, high ductility, and an environmentally friendly deposition method. However, vapor-deposited tantalum can appear in both the characteristic body-centered-cubic phase found in the bulk material, and in a very brittle and less desirable "beta" phase. Presence of the beta phase in bore coatings is considered undesirable because of its brittleness and resulting failure as the coating is stressed.

A high-rate triode sputtering system with a cylindrical coating geometry was used to produce thick tantalum coatings on 4340 steel, smooth bore cylindrical substrates. A systematic series of tests was performed to evaluate the effects of sputtering gas species (argon, krypton, xenon) and substrate temperature (100° to 300°C) during deposition on the phase and microstructure of the coatings. Heavier sputtering gases and higher substrate temperatures were found to promote the formation of body-centered-cubic phase tantalum coatings. Use of a movable target assembly was shown to promote the production of dense, single-phase tantalum coatings.

14. SUBJECT TERMS

Sputtering, Tantalum, Triode, Alpha-Tantalum,
Beta-Tantalum, Micrographs

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13. ABSTRACT *(Maximum 200 words)*

Cannons with bore coatings are necessary to reduce erosion in current and future high-performance combat systems. In 1996, we developed a unique erosion model for cannons with bore coatings. Since that time, our results from this model have been published for a number of important Army and Navy gun systems with bore coatings. The erosion model for cannons with bore coatings is guided and calibrated and correlates very well with considerable gun system firing data and subsequent laboratory analysis of fired specimens. Our confidence in the model has grown yearly such that we have decided to publish the details of this model. Coated cannon bore erosion does not simply proceed in an outward to inward progressive ablative fashion, since coatings typically spall instead of progressively ablate. This is the only known erosion model for cannons with bore coatings to account for all aspects of the typical firing-induced cannon erosion mechanism. The typical mechanism includes:

- Heat-check cracking of the bore coating
- Bore coating shrinkage leading to progressive widening of these cracks
- Combustion gas-induced interface degradation of the exposed substrate metal
- Abrupt interfacial spalling of the bore coating platelets due to linked interfacial degradation that forms pits
- Subsequent substrate metal gas wash-to-erosion condemnation

A very fine bore coating crack provides a narrow combustion gas path to the metal substrate thus producing limited interfacial substrate degradation. In contrast, a progressively widened/extended bore coating crack due to firing-induced bore coating shrinkage provides a wide combustion gas path to the metal substrate producing substantial interfacial substrate degradation. The purpose of this report is to review typical cannon erosion mechanisms, highlight the resultant cannon coating erosion model, show how this very critical coatings model incorporates into our overall cannon erosion code, and provide an example. The example is an updated erosion prediction for the experimental nonablative M829E3 kinetic energy tank round with and without HEAT-type rounds. The presence of HEAT-type rounds significantly alters the M829E3 erosion pattern compared to their absence.

14. SUBJECT TERMS

Cannon Coatings, Erosion Modeling, M829E3 Erosion Simulation

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13. ABSTRACT *(Maximum 200 words)*

The firing of any gun, electromagnetic or otherwise, imparts substantial momentum to the launcher, and ultimately the weapon platform. The objectives of the future combat system program call for similar lethality to a current heavy tank on an extremely lightweight vehicle of nominally twenty tons. Prior experience with the M551 Sheridan, a light tank first put into production by the United States in 1966, raises concern that firing large caliber armaments from light vehicles may result in unacceptable crew discomfort and vehicular reaction during recoil. This report provides a future combat system armament integration perspective for railgun recoil.

14. SUBJECT TERMS
Railgun Recoil, Mechanical Shock Isolation,
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